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TECHNICAL REPORT

AN EVALUATION OF ELECTRICALLY HEATED HANDWEAR

by

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Abstract: This study compared the responses of eight subjects wearing prototype electrically heated gloves and unheated handwear at 0 C, -9 C and -18 C. The premise of the study was that the electrically heated gloves would maintain hand warmth at least equal to bulkier issue gloves, thus enhancing performance by reducing handwear bulk. Finger temperatures and endurance time were measured while the subjects wore either a battery-powered electrically heated glove or an issue Intermediate Cold-Wet Glove (ICWG). The test plan was to test in 2 day blocks for each temperature, with half the subjects wearing the prototype glove and the other half the control ICWG glove on each day. Additional testing was done with the unheated prototype glove and a combination of the heated liner with the ICWG shell. The heated prototype glove was better than the control glove at 0 C and provided as much or slightly more thermal protection than the control glove at -9 C. It was not a viable option at -18 C. The combination of the heated liners with the insulated ICWG shells was also better relative to the unheated ICWG.

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Human subjects participated in these studies after giving their free and informed voluntary consent. Investigators adhered to AR 70-25 and USAMRDC Regulation 70-25 on Use of Volunteers in Research.

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Protocols involving the use of human volunteers as test subjects require the involvement of a large staff. The authors would like to acknowledge the contributions of the following individuals who assisted in the protocol: SGT K.R. Schafer, SGT W.F. Allison and Mr. J.A. Gonzalez. We would also like to thank Ms. D.M. Danielski for assistance with the manuscript and Ms. L.L. Lameka for assistance with the recruitment of test subjects. Finally we would like to thank our volunteer test subjects, whose participation made this study possible.

EXECUTIVE SUMMARY

This study compared the responses of eight sedentary test subjects wearing prototype handwear with electrically heated liners to their responses while wearing unheated handwear. All subjects wore the Extended Cold Weather Clothing System (ECWCS). Test environments were 0°C, -9°C and -18°C, with a light wind of 1.1 $m \cdot s^{-1}$. The hypothesis of the study was that the electrically heated gloves would maintain adequate hand warmth equal to or greater than bulkier unheated issue gloves despite less intrinsic insulation. An underlying assumption was that by reducing handwear bulk while maintaining functional finger temperatures (~15°C), the prototype heated gloves will enhance performance of tasks requiring manual dexterity. Finger temperatures and endurance time (ET) were measured while the subjects wore either a battery-powered electrically heated glove or an issue Intermediate Cold-Wet Glove (ICWG). The ICWG was used as the experimental control. The prototype "glove" consisted of a heated inner liner under a second outer glove or shell of similar material. Each layer of the prototype glove was slightly thicker than the liner of the ICWG. The subjects rested their hands palms down at heart level on nylon mesh beds stretched over a plastic frame.

The basic study design was to test the environments sequentially, starting with the warmer 0°C environment, but counter-balancing the presentation by having half the test subjects wear the prototype glove and the other half the control glove on each day. The rationale for starting with the warmer conditions was to minimize test subject exposure to cold in the event of glove failure. In addition to the basic test plan, all subjects were to test the unheated prototype glove on one test day and a combination of the heated liner with the ICWG shell on another test day. The third -9°C test environment was added to the protocol when the heated gloves were found ineffective at -18°C.

The heated prototype glove was effective at 0°C. Wearing the heated glove appeared to slow or moderate the impact of cold exposure at -9°C. The heated glove provided as much or slightly more thermal protection than the control glove at -9°C when the heat element functioned properly. It was not a viable handwear option at -18°C. The most promising result was the improved performance of the heated liners when combined with the heavier insulation of the ICWG shells relative to the unheated ICWG. There was a design flaw in the prototype heated liner which resulted in hot-spots. The problem may be related to subject activities during dressing, and must be identified and corrected before the design will be suitable for general issue to a military population.

I. INTRODUCTION

A. PURPOSE

The purpose of this study was to evaluate the feasibility of a prototype electrically heated handwear for use by Army personnel during cold-weather operations. Individual data will include finger and hand temperatures, rectal temperature, and three skin surface temperatures. Data was also collected on the battery power supplies for the handwear.

B. MILITARY RELEVANCE

The thermal protection provided by military clothing can be separated into three categories of descending importance: survival, function and comfort. Cold weather clothing items should provide sufficient protection for survival in the most extreme conditions; soldiers should be able to function with minimal impairment during prolonged exposure within the normal range of thermal conditions and, under more moderate exposure of garrison or rear-areas, the soldiers should be sufficiently buffered from cold to be comfortable.

The ability to perform an assigned mission or task is the ultimate criterion for the military. The ability to function and the degree to which function is impaired or limited is the ultimate measure of any military clothing. It is important to survive, but a soldier that can only survive is an impedance to the overall mission who demands resources without contributing to the mission. Vanggaard (21) wrote that an individual with hands that are too cold cannot function. In conversation, Vanggaard stated more emphatically that in the Arctic, a man without functional hands is a dead man. In a military operation, individuals that are unable to function may not be literally dead, but the loss of their efforts may threaten the success of the overall mission.

Tasks that require manual dexterity begin to significantly deteriorate when finger surface temperatures fall below 15°C, and most tactile sensitivity disappears when surface temperatures reach 4.5°C (3,9). Discomfort and pain are subjective criteria that are not as readily defined. Coolness or moderate discomfort may start at approximately 26°-28°C, and responses of significant discomfort or pain begin to occur below 10°C. Subjective responses may be dependent on the total surface area affected and the local surface temperatures, thus a local skin temperature at 5°C may not elicit a subjective response of pain.

In cold environments, it is rarely possible to have handwear that will provide sufficient insulation to maintain functional hand temperatures indefinitely. In addition, heavily insulated handwear is often bulky and reduces both dexterity and tactile sensitivity. To perform tasks that require those capabilities, it is often necessary to remove handwear and work with only thin anti-contact gloves or bare hands.

The alternative solution is supplemental or auxiliary heating to offset heat loss to the environment. The use of electrically heated handwear and clothing by U.S. military personnel may be traced to WWI (18), but electrically heated handwear is still under development because of the unsatisfactory performance of previous prototypes.

Target users include military populations that are exposed to cold environments, perform tasks that require manual dexterity and/or tactile sensitivity, and have access to sufficient resources to replace or recharge handwear power supplies. Livingstone et al. (11) used a survey of 1047 Canadian Forces personnel to determine that in situations where cold presented functional problems, auxiliary heat would be beneficial. That population would include aviators, armored vehicle crews, equipment operators, and mechanics at forward or outdoor repair facilities. Haisman (6) cites the use of electrically heated handwear in the UK by military air crews, missile fuel handlers and arctic maintenance personnel. Scott (16) adds armored vehicle and gun crews to the list of potential UK military users. Scott included the operators of cranes and fork lifts as potential civilian users. Other potential applications are military or civilian personnel performing duties in cold environments, including cold storage workers, fisheries workers, commercial and recreational snowmobilers, hunters and recreational skiers.

C. BACKGROUND

There are two options for maintaining adequate hand temperatures. One is to conserve the heat stored or generated within the body tissues by slowing the rate of heat loss to the colder environment with insulation. In some cases, particularly when excess heat is generated in other parts of the body by exercise, an approximate equilibrium may be established with adequate insulation. Under other conditions, especially when the individual is sedentary, insulation merely prolongs endurance until surface temperature drops to the tolerance limits (20,5). Van Dilla et al. (20) established that in many cold environments it was impossible to obtain enough insulation to maintain a functional hand temperature by passive warming. They calculated that due to the limitations imposed by the maximum possible thickness of insulating materials on each finger, no gloves could maintain finger temperature at 15.6°C for a sedentary individual if the air temperature was below -1.1°C.

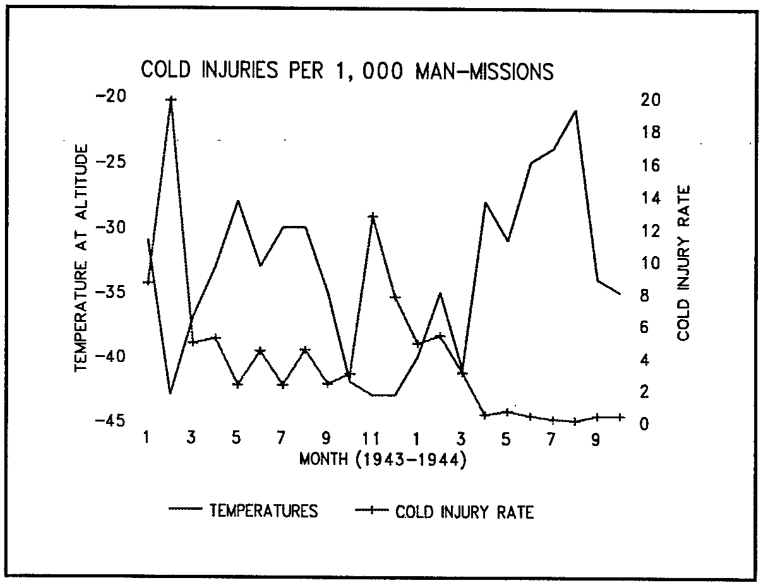
The other method of maintaining hand temperatures is to replace or offset the heat loss by supplemental or auxiliary heat input. Goldman (5) reiterated Van Dilla's arguments and emphasized that the answer was active heating. He states that this is the only effective way to maintain hand temperatures during a sustained exposure to extreme cold. Goldman (5) set the requisite heat input at 3 W to maintain hand temperatures of 4.4°C at an air temperature of -40°C. Other conditions were arctic clothing (4.3 clo), a wind speed of 4.5 $m \cdot s^{-1}$ and sedentary activities. A relatively comfortable hand temperature of 26.7°C would require a power input of 10 W per hand. Madnick and Park (12) reported on the same system that 5 W per hand was adequate to maintain hand temperatures at 15.6°C at an air temperature of -40°C and a wind speed of 1.34 $m \cdot s^{-1}$. Clark and Edholm (2) claimed that approximately 6 W per hand would be adequate to maintain dexterity at -32°C. Haisman (6) cited Clark and Edholm, but his work found that an input of 11-19 W was necessary for knitted gloves.

Civilian examples of external heat supply include catalytic hand warmers; packets of exothermic chemicals; potatoes, bags of salt or other materials heated in an oven; and electric heat supplied by batteries or other power sources. Although sales may not be excessive, battery-powered socks are a standard item in sporting goods catalogues catering to winter hunters. Electrically heated handwear was also available from at least one sporting goods catalogue in 1995.

As noted above, the development of electrically heated handwear pre-dates WWII. During WWII, the most common military users were aviators, although Pitkins (14) makes a brief reference to efforts to develop electric-heated handwear for armor maintenance personnel. Considerable emphasis was placed on the development of electrically heated clothing for aviators flying high altitude missions in unpressurized aircraft during WWII (12,18,16). Temperatures in cramped turrets below -50°C were not uncommon, and the hands might be exposed to high air velocities that further exacerbated heat loss (10). Sweeting (18) refers briefly to electrically heated gloves for pilots, obtained from the French during WWI. In addition, Sweeting cites a report that in September 1943, 32% of the 1077 casualties reported by the U.S. Eighth Air Force were victims of frostbite of the hands. Madnick and Park (12) state that Eighth Air Force cold injury casualties exceeded wound casualties for 14 months, through December 1943. The regular issue of electrically heated handwear in October 1943 (Figure 1) reduced the incidence of hand frostbite by approximately half .

A review of the literature indicates numerous efforts to develop a successful auxiliary heating system for handwear after WWII (12,6,16,18). The general consensus is that the concept has merit, but the actual products were inadequate. Causes of failure included the contradictory demands for flexibility and durability for the heating elements and problems with power supply. Failure often consisted of breakage of heating elements or hot spots. The present prototype attempts to overcome those deficiencies by utilizing a knit, metallic fabric as the resistance heating element. Other common concerns are problems with the heating power supply including weight and duty-life of batteries; tether line limitations if an external"plug-in" power supply is used; and adequate hand protection in the event of a power supply failure or depletion. Grounding and other safety issues are also an issue if the heating element is connected to a high-voltage power generator rather than a battery power supply.

Figure 1. Eighth Army Air Force, European Theater, High-altitude cold injury rate, January 1943 to October 1944 [from Table 52, Link and Coleman (10)]



II. METHODS AND MATERIALS

A. GENERAL

1. Overview

Testing was conducted in the Doriot environmental chamber at the U.S. Army Research, Development and Engineering Center (NRDEC) in Natick, MA. The basic test procedure was to dress test volunteers in the Extended Cold Weather Clothing System (ECWCS) with either a control issue winter glove or prototype glove. The control glove was the Intermediate Cold/Wet Glove System (ICWG). The volunteers entered the cold chamber and sat for 125 minutes while surface finger and hand temperatures were collected. Arms and hands were supported at heart level using a combination of netting and flat screening or mesh. The hands were supported to prevent both blood pooling or drainage in the lower arms and fingers, which could have modified heat transfer to the fingers. Volunteers sat for 125 min or less. The initial 5 minutes was used as a baseline. Independent parameters were air temperature and glove type. Dependent parameters were skin temperatures including right and left middle finger, right little finger, wrist, palm and back of hand, and tolerance or endurance times (ET). Values were also collected for three skin temperatures ($\bar{T}_{sk}$) on the body surface and rectal temperature (T_{re}).

2. Volunteer Population

Eight military volunteer subjects were selected to participate. The volunteers were healthy, fit soldiers between the ages of 18 and 35. Prospective volunteers were fully informed by a verbal presentation regarding the test methods and safety concerns. All volunteers signed a written consent form indicating their freely given consent to participate in the study.

3. Health and Safety of Volunteers

The procedures for this study conformed to the limits specified in the USARIEM Type Protocol for Human Research Studies of Thermal Stress (19). Volunteers received a physical examination and were screened for a prior history of cold injury, which would have excluded them from the study on the basis of previous cold injury. Rectal, finger and toe temperatures were monitored throughout the tests and acclimation. Finger and toe surface temperatures were not allowed to drop below 5°C. Rectal temperatures could not fall below 35.5°C. Each volunteer was afforded the unconditional opportunity to voluntarily withdraw from any test session or the entire study at any time without suffering any prejudicial treatment. The subjects were removed from a test by a test observer or the medical monitor. The normal rationale for withdrawal of a subject by other personnel was observation of verbal or physical symptoms of excessive stress such as violent prolonged shivering, stumbling or disorientation, and verbal or non-verbal indications of pain or extreme discomfort.

4. Prototype Description

An earlier version of the Electrically Heated Handwear (EHH) System* has been described by McCormack and Webbon (13). Details of the glove, including materials and construction method, were/are considered proprietary. Individuals requesting more specific information should contact the developer (Federal Fabrics-Fibers, Inc., 21 Marie Drive, Andover, MA 01810). The seamless, knitted gloves are divided into heated area and unheated areas. The heating elements were knit into the thumb and finger areas. The remaining unheated areas are knit with synthetic yarn. A thin knit overglove of synthetic fiber was worn over the heated EHH glove liner. The EHH glove liner has built-in electronic controls. Each digit has its own temperature measurement and control. An integrated circuit (IC) chip with an imbedded thermocouple monitors temperature and a second IC chip modulates the power delivered to the individual digit. Copper wires carry electricity to the fingers to the embedded heater elements. The set-point temperature for power input during the tests was 22.5°C. The EHH system is powered by a 6 Volt DC battery power supply (Procell PC918; Duracell, Bethel, CT).

The insulation of an earlier variation (Phase I prototypes) of the EHH was measured with and without power input and compared to the winter Combat Vehicle Crewman Glove (CVC) by the Navy Clothing and Textile Research Facility (NCTRF). The values obtained by NCTRF (17) were 0.59 (±0.02) clo for the unheated prototype glove. An "apparent clo" for the same glove with a 6 V power supply was 1.06 (± 0.03) clo. The NCTRF value for the CVC glove was 0.78 (±0.01) clo. Based on the differences in insulation, NCTRF concluded that there was a significant difference in thermal protection between the EHH and CVC handwear. Testing conditions differed from those standardized by USARIEM (15), but the intrinsic insulation estimates obtained by subtracting the bare-hand values from the total insulation (I_T) indicate that USARIEM and NCTRF values for the CVC glove agree to within 0.1 clo. Table 1 lists the total dry insulation (I_T) values for the different handwear ensembles used in this study without the addition of external electric heating.

Table 1. Total insulation (I_T) values for handwear (no batteries)

Handwear ensemble	I_T (clo)
Intermediate Cold Wet glove w/ liner	1.1
Intermediate Cold Wet glove w/ heated liner	1.1
Heated glove ensemble (shell + heated liner)	0.5
Heated liner only	0.5

B. CHAMBER TESTING

1. Test Design

The test schedule is presented as Table 2. The basic test plan was to present the environments sequentially, starting with the warmer 0°C environment, but counterbalancing the presentation by having half the test subjects wear the prototype glove and the other half wear the control glove on each day. Each test environment was run as a discrete block, one air temperature at a time, starting with the warmest 0°C environment. On each test day, half of the volunteers wore the prototype and the other half of the population wore the control glove. On the following day, each group wore the other glove treatment. By initially testing in the warmer environment, a finding of any gross deficiencies in the thermal protection or a prototype malfunction is more likely to occur first in the less extreme environment, thereby reducing the level of risk to the volunteers. The final test at -18°C was a combination of the heated prototype liner with the insulated outer shell of the ICWG. This test condition was conducted as an additional test session. To further address the question regarding the level of cold protection afforded by the prototype if the power supply should fail or be depleted, the unheated prototype was tested after the testing of the heated prototype versus the control is completed. The test of the unheated prototype was at the warmest (0°C) chamber air temperature. The -9°C environment was added to the test plan when it became apparent that -18°C was too cold of an environment for the prototype EHH. Due to problems with the EHH, all powered tests were suspended after the first day of testing at -9°C.

2. Test Scenario

a. Pre-Test. On test days, after reporting to the dressing area, volunteers were asked to complete a pre-test health symptoms questionnaire. After completing the questionnaire, subjects were weighed nude. They were then instrumented and dressed for the test session. Subject instrumentation consisted of a chest band heart-rate monitor with a wrist-mounted display, a rectal temperature thermistor and ten thermocouple surface thermometers (right middle and little finger, back and palm of hand, ventral wrist, left middle finger, big toe, chest, forearm and calf). Prior to entering the test chamber, all subjects were weighed fully clothed and an instrument-check was run.

b. Chamber Testing. The test environments were at air temperatures of 0°C, -9°C and -17.8°C. The simulated wind speed for all environments was 1.1 $m \cdot s^{-1}$. Volunteers entered the test chamber, and their instrument leads were connected to the data acquisition system. The volunteers were seated on metal chairs with backrests. The 5 minute baseline began when all subjects were connected to the data acquisition system and the first complete set of temperatures were displayed. Each volunteer placed their hands on a flat mesh surface that was supported by netting stretched over an 18" x 36" plastic frame. The frames were suspended from the chamber ceiling. The height of the mesh was adjusted so that both hands were positioned at heart level. The subjects leaned slightly forward with bent arms onto the suspended mesh so that their upper body weights were lightly supported by the forearms. This is a relatively comfortable position and the volunteers were able to shift their weight slightly back and forth so that body weight is shifted between the buttocks, the shoulders and the forearms. However, to maintain some control over movements which may impact circulation to the hands, the volunteers were discouraged from frequently shifting back and forth. The first 5 minutes prior to administration of the first thermal sensations questionnaire were considered a baseline period. The thermal sensations questionnaire was given every 15 minutes. Subjects remained seated in the test chamber until they completed 125 minutes of exposure, voluntarily withdrew from the test session or they were withdrawn by the test staff or medical monitor. Criteria for removal of volunteers by test observers included instrument readings at the specified physiological limits for heart rate and rectal or surface temperatures, excessive or prolonged shivering, or indications of extreme discomfort or pain. In addition to data on volunteer responses, the voltage and current of the battery power supplies was measured and recorded on the data acquisition system during the chamber sessions. The voltage and current measurements indicated when there was heat input into each glove.

c. Post-test Measurements. Volunteers exited the test chamber and were weighed fully clothed. After removal of all clothing and instrumentation, their nude weight was measured

Table 2. Test Schedule

T_{ch} (°c)	odd-glove	even-glove
0	prototype w/ heat	ICWG
0	ICWG	prototype w/ heat
-18	prototype w/ heat	ICWG
-18	ICWG w/ heated liner	
0	prototype w/o heat	
-9	prototype w/ heat	ICWG
-9	ICWG	no test
0	make-up prototype w/o heat	make-up ICWG

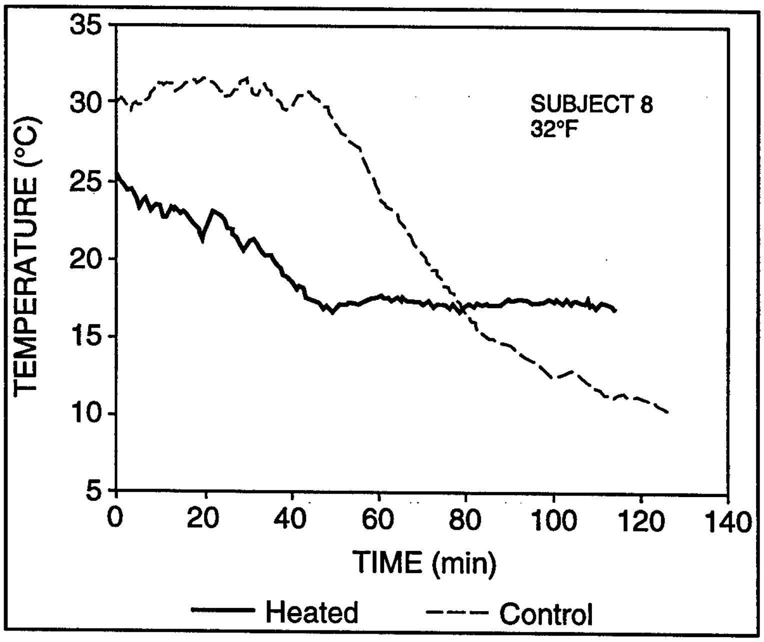
III. RESULTS AND DISCUSSION

A. GENERAL RESULTS

1. Overall Trends

The hypothesis of the study was that the electrically heated gloves would maintain adequate hand warmth equal to or greater than bulkier unheated issue gloves despite less intrinsic insulation. Although not tested during this study, an underlying assumption was that by virtue of their reduced bulk and the maintenance of functional finger temperatures (~15°C), the prototype heated gloves would provide greater dexterity for the performance of tasks requiring manual dexterity. Figure 2 illustrates a properly functioning glove that maintains the subject's mean finger temperature at a functional equilibrium temperature.

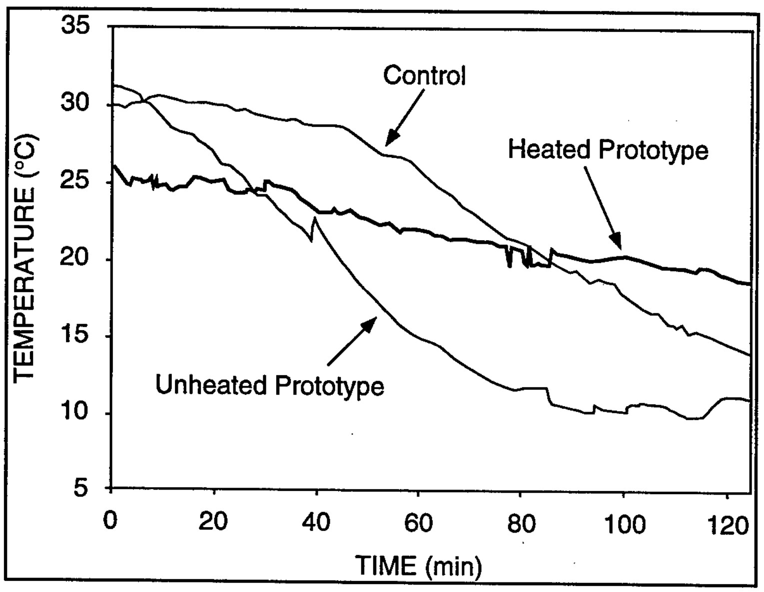
Figure 2. Comparison of finger temperatures (°C) based on the unweighted average for three fingers during testing at a chamber temperature of 0°C (32°F) for Subject 8



2. 0°C (32°F) Environment

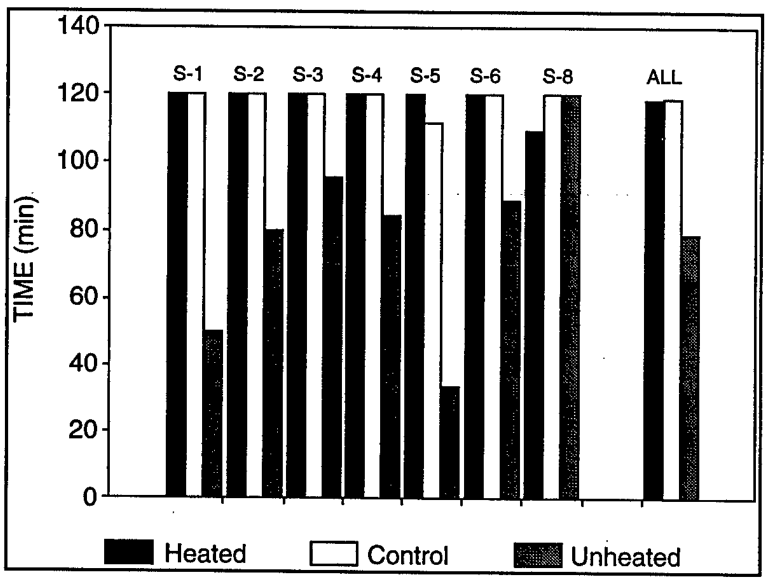
At the end of 2 h of exposure at 0°C (32°F), data indicate that the heated gloves were maintaining finger temperatures higher than those experienced while wearing either unheated prototype gloves or the better insulated Intermediate Cold-Wet Gloves (ICWG) used as the experimental control when the heated prototype gloves functioned properly,. Figure 3 compares mean finger temperatures values for the three conditions at 0°C. The population size used to calculate the mean finger temperature values for the unheated prototype decreased as subjects withdrew from the test over time. Consequently, the lines represent the mean temperatures for a gradually decreasing subject population and are shown primarily to indicate the general trend.

Figure 3. Mean finger temperatures (°C) for the three handwear treatments (heated prototype, unheated prototype and unheated ICWG control) based on the three finger average for all subjects (N=7)



a. Comparison of Endurance Times Between Handwear Treatments. Figure 4 compares endurance times for individual subjects under the same conditions plus mean data values. Despite cooler initial finger temperatures, there was no meaningful difference in total exposure or endurance time (ET) between the heated and ICWG control handwear. At 0°C, the advantage to heated handwear would be the presumed increase in dexterity. The data also support the expectation that the heated prototype is warmer than the unheated prototype. An exception was Subject 8, who actually had warmer fingers and longer endurance in the unheated prototype. The mean ET (with SD) for the heated prototype was 117 (5) min, for the unheated prototype, 79 (29) min, and for the unheated ICWG control, 120 (0) min. All values are for 7 subjects.

Figure 4. Mean Endurance Times (ET) for all three handwear treatments (heated and unheated prototype plus control ICWG) for 7 subjects. Only the difference between the unheated prototype and the other handwear treatments is significant (p>0.001)



b. Finger Temperatures. Table 3 presents the terminal finger temperatures for subjects in the heated prototype and control ICWG gloves at 0°C (32°F). One caveat concerning the final finger temperatures is that for the battery heated prototype, the last recorded finger temperatures sometimes dropped abruptly because the battery had to be disconnected to remove the subject. To overcome this problem, the last recorded values for finger temperatures were not used to compile the table. Subject 7 was unable to participate in as many test sessions as other subjects. Consequently, in Table b, values are presented for subject populations without Subject 7 to allow a better comparison with other test conditions reported for only 7 subjects. However, it is also beneficial to calculate mean performance with a slightly increased subject population size (n=8).

Table 3. Comparison of the effects of the heated prototype versus the ICWG on ET and final finger temperature values for the 7 subjects that completed both test exposures.

Table 3a. COMPARISON BETWEEN GLOVES AT 0°C (32°F)

	HEATED PROTOTYPE GLOVE					CONTROL INTERMEDIATE COLD-WET GLOVE				
SUBJECT	ET MIN	RMF °C	RLF °C	LMF °C	3-F* °C	ET MIN	RMF °C	RLF °C	LMF °C	3-F °C
1	120	11.84	17.70	14.57	14.70	120	11.24	11.12	22.37	14.91
2	120	13.32	11.49	14.93	13.24	120	20.20	15.25	21.44	18.96
3	120	17.16	23.07	19.43	19.89	120	9.66	11.82	15.91	12.46
4	120	25.85	25.83	18.07	23.25	120	21.78	15.07	16.89	17.92
5	111	20.23	18.58	23.41	20.74	120	10.99	10.83	10.43	10.75
6	120	17.24	26.39	21.55	21.73	120	10.42	11.24	10.69	10.78
8	109	22.88	17.53	10.48	16.96	120	10.79	10.37	9.75	10.30
X	117	18.36	20.08	17.49	18.64	120	13.58	12.24	15.35	13.73
SD	5	5.01	5.32	4.47	3.75	0	5.11	2.04	5.27	3.59

* 3-F is unweighted average of right-middle finger (RMF), right little finger (RLF) and left-middle finger (LMF) temperatures.

Table 3b. Unheated prototype gloves at 0°C (32°F)

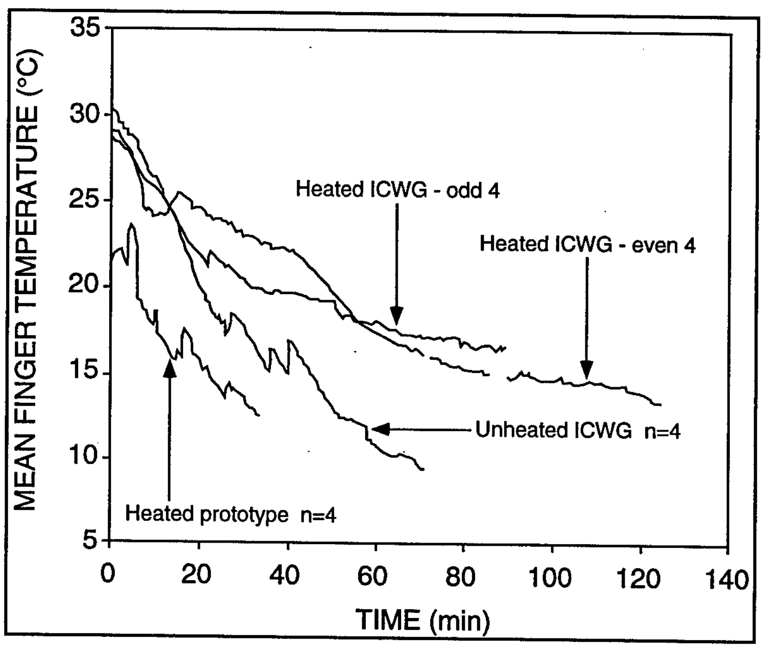
	UNHEATED PROTOTYPE GLOVE									
SUBJECT	ET MIN	RMF °C	RLF °C	LMF °C	3-F* °C	ET MIN	RMF °C	RLF °C	LMF °C	3-F °C
1	51	20.78	22.03	8.93	17.24					
2	80	13.55	13.57	19.41	15.51					
3	96	9.27	10.07	9.30	9.55					
4	84	12.21	9.18	9.26	10.21					
5	34	10.67	11.62	23.61	15.30					
6	89	8.52	8.67	8.89	8.69					
7						33	13.78	12.28	12.04	12.70
8	120	12.54	11.02	8.86	10.81					
	N=7, SUBJECT 7 NOT INCLUDED					N=8, SUBJECT 7 INCLUDED				
$\bar{X}$	79	12.51	12.31	12.61	12.47	73	12.67	12.30	12.54	12.50
SD	29	4.07	4.59	6.21	3.43	31	3.79	4.25	5.75	3.18

* 3-F is unweighted average of right-middle finger (RMF), right little finger (RLF) and left-middle finger (LMF) temperatures

3. -18°C (0°F) Environment

At -18°C, conditions were too cold for any practical use of the prototype gloves. The 4 subjects wearing the heated prototype had a mean ET of 16 min vs. 46 min for the ICWG. Rather than exposing test subjects to unrealistic conditions, the second half of the subject population was not tested with the heated prototype at -18°C. Only the 4 subjects that tested with the heated prototype glove completed the counter balanced set of exposures wearing both the prototype and control gloves. Figures 5 and 6 compare data for mean finger temperatures and endurance times for this test series at -18°C. The third handwear condition, the ICWG with the prototype heated liner at -18°C described below, is also included in Figure 5. Two sets of gloves malfunctioned for Subject 5 (Figure 7). If the heated prototype gloves had functioned properly, the mean ET would probably have been greater and variability should have been reduced. The same situation occurred in the -9°C environment (Figure 11). The advantage of the heated liner relative to the ICWG with an unheated liner is apparent in Figures 8 and 9.

Figure 5. Mean finger temperatures for subjects wearing heated prototype gloves, unheated ICWG and the ICWG heated by with the prototype liner at -18°C. Individual values based on unweighted average of three finger temperature measurements



All subjects tested at -18°C using the combination of the heated glove liner with the outer shell from the ICWG. Figure 5 plots mean finger temperatures for all three handwear treatments. Figures 7 and 9 compare the ICWG with a heated liner to the two standard handwear treatments, a heated prototype and an unheated ICWG. As Figures 5-9 indicate, the combination of the heated prototype liner with the outer shell of the ICWG improved both endurance times and mean finger temperatures. The difference in ET was significant ($p > 0.0221$). Tables 4a and b present subject data for all test days at -18°C (0°F). Again note (Figures 8-9) that as the subjects dropped out as the test periods progressed, the lines represent a running average of the remaining subjects. Breaks or abrupt changes often indicate when subjects drop out of the tests.

Figure 6. Exposure Time (ET) values by group (N=4 each), comparing the ICWG heated with the prototype liner to either the heated prototype ensemble (ODD) or the unheated ICWG (EVEN) at -18°C (0°F)

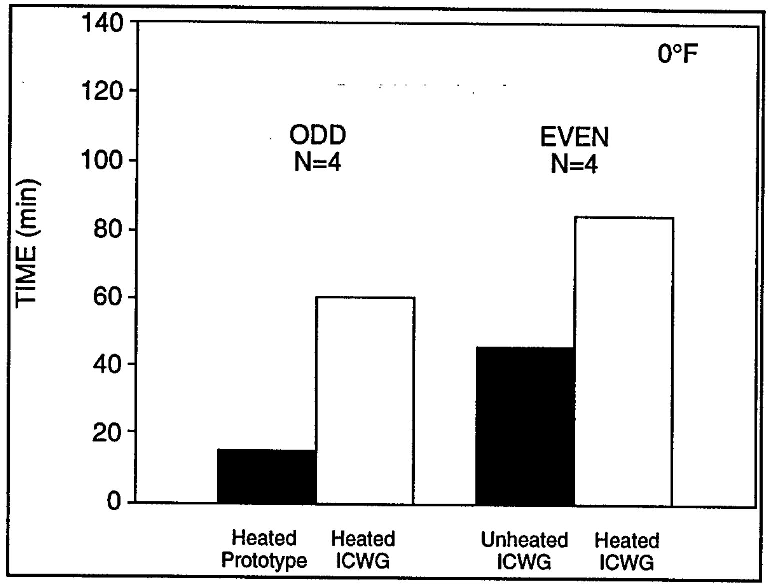


Figure 7. Individual and group values (N=4) comparing Exposure Time (ET) in the heated prototype to the ICWG heated by the prototype liner at -18°C (0°F). This figure illustrates the advantage of a better insulated outer shell

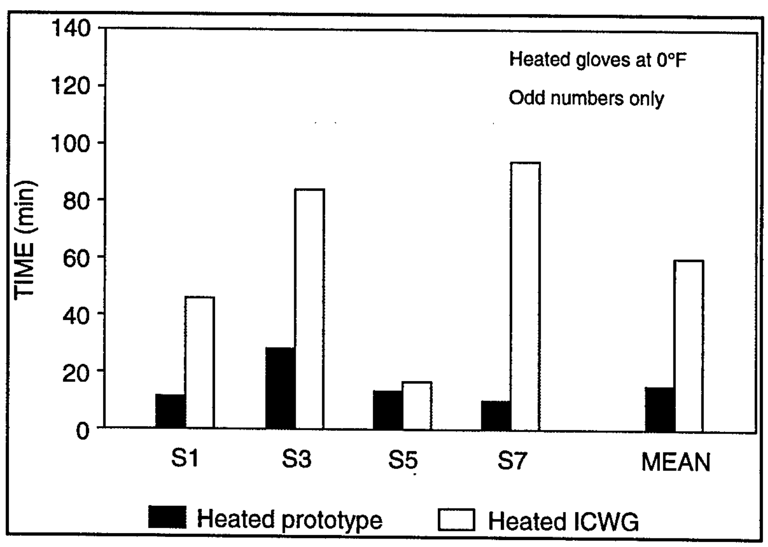


Figure 8. Mean finger temperatures (°C) for subjects wearing ICWG with and without a heated liner. Individual values based on average of three finger temperature measurements

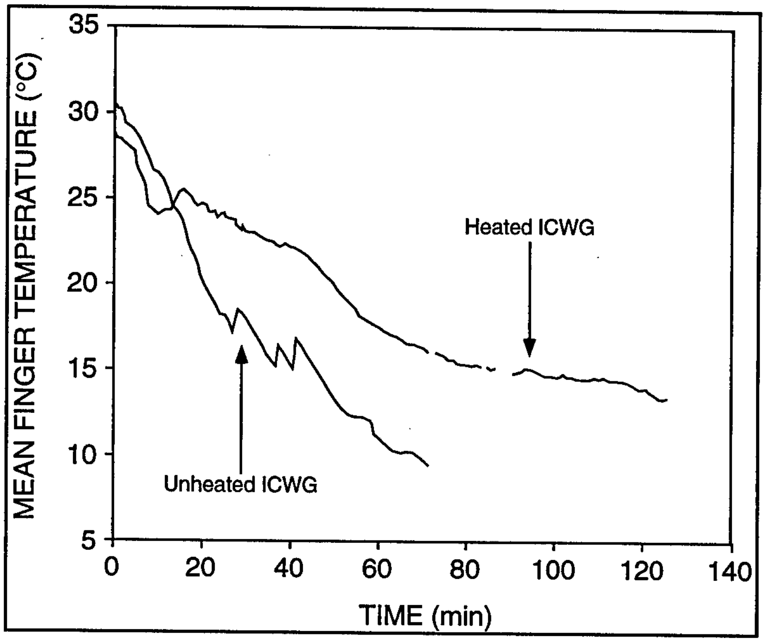


Figure 9. Individual and group values (N=4) comparing Exposure Time (ET) in the unheated ICWG to the ICWG heated by the prototype liner at -18°C (0°F). This figure illustrates the increase in ET gained by using a heated liner with the same well-insulated ICWG shell

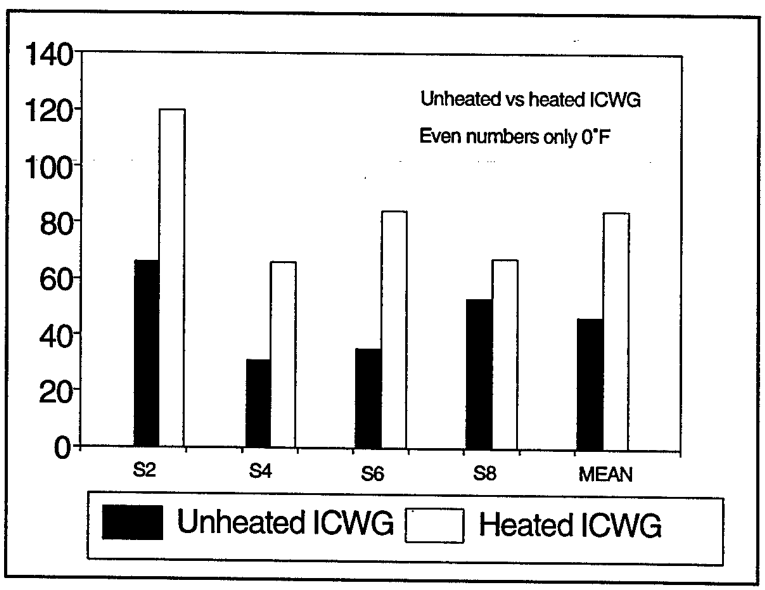


Table 4a. Comparison between gloves at -18°C (0°F)

SUBJECT	HEATED PROTOTYPE GLOVE					HEATED INTERMEDIATE COLD-WET GLOVE				
N=4 (ODD)	ET MIN	RMF °C	RLF °C	LMF °C	3-F °C	ET MIN	RMF °C	RLF °C	LMF °C	3-F
1	11	8.83	8.96	18.23	12.01	46	22.73	22.47	17.29	20.83
3	29	10.84	8.20	16.84	11.96	86	13.52	8.88	18.32	13.57
5	13	14.18	14.29	21.67	16.71	18	20.19	22.33	15.28	19.27
7	10	13.88	18.81	11.50	14.73	95	20.31	24.55	14.48	19.78
X̄	16	11.93	12.56	17.06	13.85	61	19.19	19.56	16.34	18.36
SD	9	2.56	4.97	4.23	2.30	36	3.96	7.19	1.77	3.26

Table 4b. Comparison between gloves at -18°C (0°F) - cont'd

SUBJECT	UNHEATED INTERMEDIATE COLD-WET GLOVE					HEATED INTERMEDIATE COLD-WET GLOVE				
N=4 (EVEN)	ET MIN	RMF °C	RLF °C	LMF °C	3-F °C	ET MIN	RMF °C	RLF °C	LMF °C	3-F
2	66	8.79	5.79	14.20	9.59	120	13.01	11.71	15.57	13.43
4	31	11.10	10.28	10.17	10.51	67	20.76	25.00	12.96	19.58
6	35	10.53	5.49	17.43	11.15	86	20.53	15.45	9.96	15.31
8	53	16.52	15.40	6.60	12.84	68	10.77	15.37	12.00	12.71
X̄	46	11.73	9.24	12.10	11.02	85	16.27	16.88	12.62	15.26
SD	16	3.34	4.65	4.72	1.37	25	5.14	5.69	2.33	3.08

4. -9°C (16°F) Environment

As the test progressed, it was clear that the selected test conditions (0° and -18°C) were either too warm for the ECWCS uniform or too cold for an optimal demonstration of the prototype gloves potential. The most viable option was to amend the test protocol to repeat the testing in a third environment, -9°C (Table 5). The two initial chamber temperatures appeared to bracket the optimal condition. At this point in testing, there had been some indication of hot spots in the prototype gloves, but examination of the hands of affected subjects gave no visible indication of excess heat.

Table 5. Comparison between gloves at -9°C (16°F).

SUBJECT	HEATED PROTOTYPE GLOVE					CONTROL INTERMEDIATE COLD-WET GLOVE				
N=4	ET MIN	RMF °C	RLF °C	LMF °C	3-F °C	ET MIN	RMF °C	RLF °C	LMF °C	3-F
1	51	10.91	12.99	6.67	10.19	47	7.42	7.63	7.99	7.68
3	83	13.79	15.32	15.69	14.93	63	18.82	8.83	10.79	12.81
5	46	13.37	21.23	15.99	16.86	43	12.15	9.67	11.61	11.15
7	7**	18.05	17.55	12.66	16.08	72	10.16	12.12	21.39	14.56
$\bar{X}$	47	14.03	16.77	12.75	14.52	56	12.14	9.56	12.95	11.55
SD	31	2.97	3.51	4.32	2.99	14	4.86	1.90	5.84	2.93

**Glove failure - subject withdrawn.

Figure 10. Comparison of endurance times (minutes) for all odd numbered subjects while wearing heated prototype glove or unheated ICWG

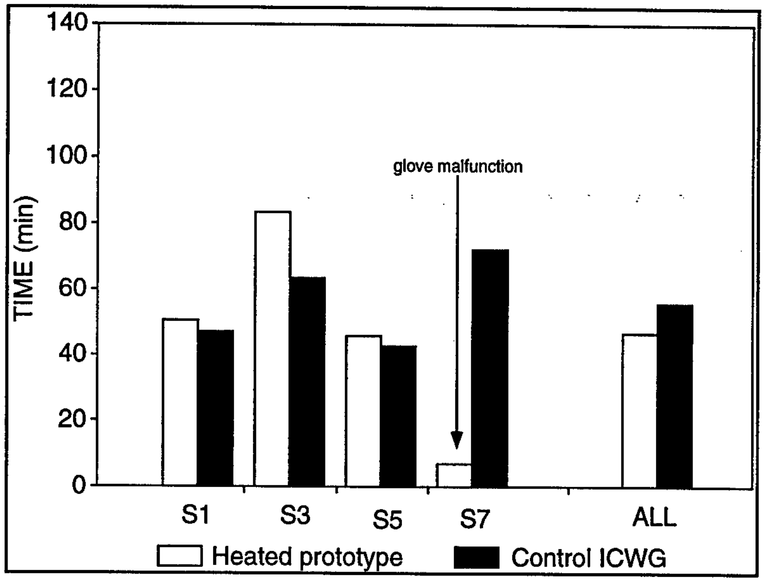


Figure 11. Mean finger temperatures (°C), based on average of three fingers, for Subject 1 while exposed to -9°C while wearing the heated prototype glove and the unheated ICWG

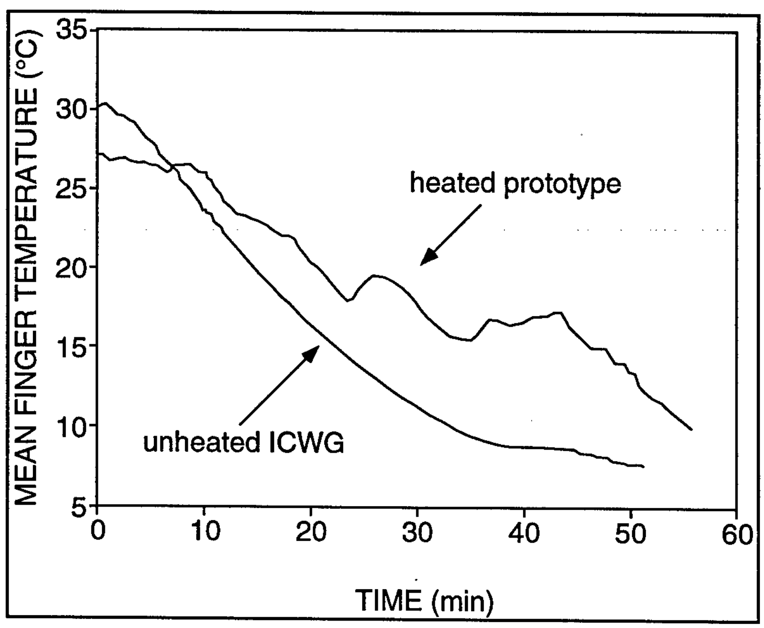
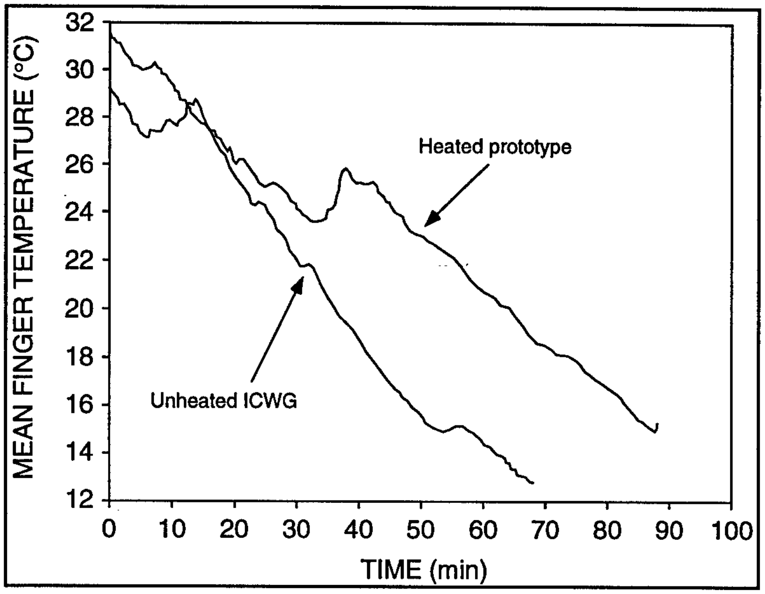


Figure 12. Mean temperatures (°C), based on average three fingers, for Subject 3 exposed to -9°C while wearing the heated prototype glove and the unheated ICWG



5. EHH Failure

On the 6th test day (19 NOV 96) a test subject indicated that a heated glove was excessively hot. The glove was quickly disconnected from the battery and removed. There was a reddish area on one thumb which was described by the medical monitor as a first degree burn. Upon completion of the testing for that day, the decision was made to suspend further testing of battery powered gloves. The 4 subjects who wore the heated prototype at -9°C completed their test series by testing with the unheated control ICWG the following day, but all other testing except make-up tests with unheated gloves ended. Table 5 and Figure 10 provide data for these subjects at -9°C. At -9°C the heated prototype glove appeared to slow or moderate the rate of finger cooling, but as the plot for endurance times and for the finger temperatures of subjects 1 and 3 indicate there was no apparent equilibrium with either the prototype or the control glove. Figures 11 and 12 compare the mean finger temperatures for individual subjects that completed the original counter-balanced test series.

The occurrence of hot spots (para 8), which resulted in the termination of prototype testing, and other subject responses of uneven or non-functioning heating suggest that the prototype gloves were not fully functional despite initial screening by one co-investigator to ensure that the gloves were functioning properly.

6. Battery Power

As an additional check, battery voltage and current drawn by the glove was measured every 30 seconds. These data provide an independent indication of glove function. Figures 13 and 14 plot mean finger temperatures versus battery demand in volt-amps for two individual cases. The initial period of "hunting" as the glove heaters are switched on and off are eventually replaced by a relatively steady power draw. Figure 13 represents a case where the glove initially drew little power whereas Figure 14 represents a case where power was essentially drawn from the onset of testing. The data for the batteries are the average for the two hands and have been modified by a simple weighted smoothing function.

Figure 13. Battery draw and average finger temperatures for Subject 1 wearing heated prototype glove ensembles at 0°C (32°F)

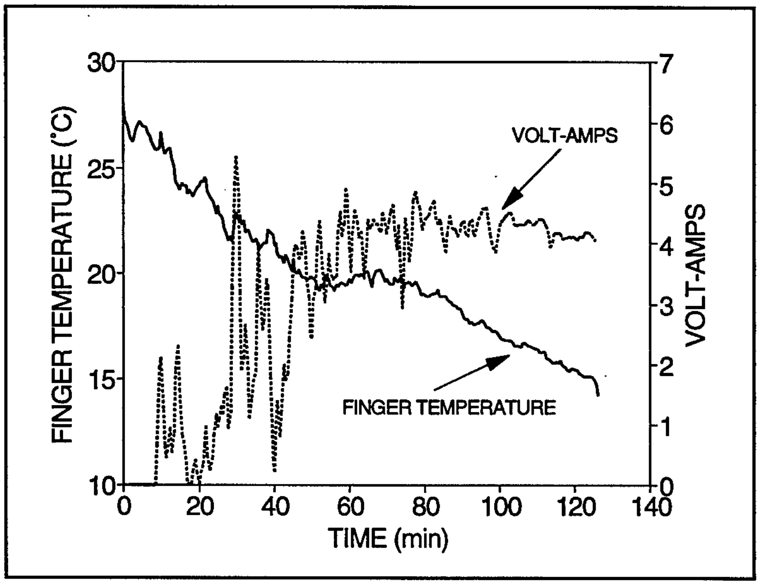
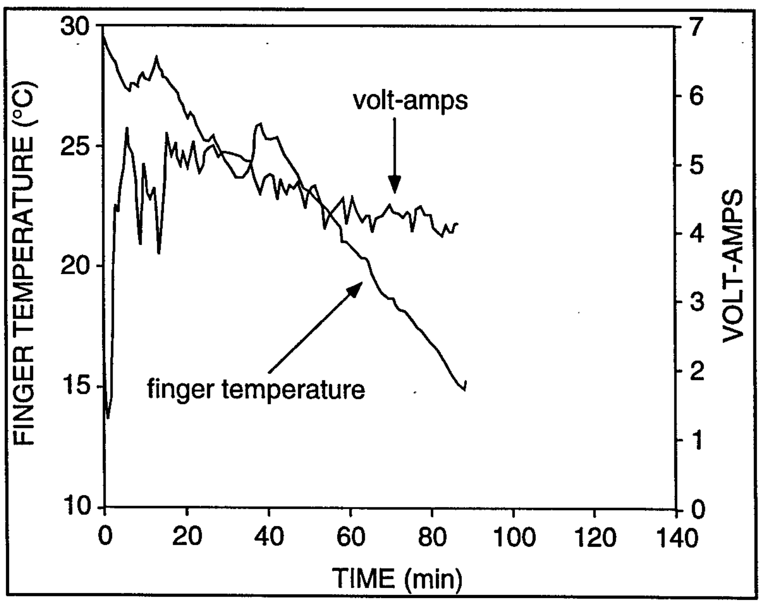


Figure 14. Battery draw and average finger temperatures for Subject 3 wearing ICWG shell over heated liner at -9°C (16°F)



B. STATISTICS

1. General Comments

A variety of problems have made statistical evaluation of the test results difficult. Large individual variability mandates the use of a repeated measures statistical model, but the reduction in the sample population to 4 subjects severely reduces the power of this test. Due to hand heat losses during the initial set-up, attempts to directly compare the decline in finger temperatures were not successful because there was no equivalent starting conditions (Figure 2). This condition was most acute in the 0°C test condition. One consequence is that any comparison of ET times is highly dependent on initial conditions. At the colder chamber temperatures, subjects whose hands became too cold during set-up were simply unable to recover.

2. Statistical Results by Environment

a. 0°C. Repeated measures ANOVA analysis was used to evaluate the relationship between ET, RMF, RLF, LMF and the combined three finger mean (3-F) in the 0°C (32°F) environment. The overall data sets were significant for ET ($p>0.001$), RLF ($p>0.014$) and 3-F ($p>0.031$). Using Tukey's Studentized Range Test (HSD) at the 0.05 level of significance to compare between data pairs, ET was significantly different (shorter) for the unheated prototype glove when compared to either the heated prototype or the ICWG. For the RLF, the heated prototype was significantly different (warmer) when compared to the unheated prototype or the ICWG. For 3-F, there was a significant difference between the heated and unheated prototypes. The unheated prototype was only tested at 0°C. The limited statistics support a conclusion that the unheated prototype provided less protection than either the heated prototype or the ICWG, and the heated prototype maintained higher finger temperatures than either the unheated prototype or the ICWG.

b. -9°C. The subject populations available for comparison at -9°C (16°F) were smaller ($n=4$), and repeated measures ANOVA method could not be used. Based on a paired T-tests, there was a significant difference ($p>0.016$) for the RLF between the heated prototype and the ICWG. The heated prototype maintained higher finger temperatures.

c. -18°C. Comments concerning sample size also apply to data from the -18°C (0°F) environment. There was no statistical support for any difference between the heated prototype and the ICWG with the heated liner. There was a significant difference in ET between the heated and unheated ICWG ($p>0.0221$).

3. Statistical Summary

Despite a lack of statistical support, the combination of the heated liner with the ICWG outer shell was clearly superior to either the thinner heated prototype or the unheated ICWG at -18°C. Although data are not available, without power the prototype liner and ICWG shell is probably equivalent in insulation to the issue ICWG. Dexterity may be reduced due to the stiffness of the heating elements in the liner. The bulk of both of these gloves would probably impair dexterity relative to the original prototype design, but these test results also suggest that the original prototype was not viable at -18°C.

IV. SUMMARY

The heated prototype glove was effective at 0°C--appeared to slow or moderate the impact of cold exposure at -9°C and was essentially ineffective at -18°C. When functioning properly , the heated prototype performed better than the control ICWG at 0°, and equaled or marginally outperformed the control glove at -9°C. The prototype performance at -18°C may have been improved if the prototypes had been operational prior to entering the chamber, or the hands had been protected by heavy overmittens or other insulation until the batteries were connected. The failure to protect the hands from cold exposure until the batteries were connected was a test design flaw.

Perhaps the most promising finding was the performance of the heated liners when combined with the heavier insulation of the ICWG shells. The practice of combining the heated liners with heavily insulated shells could be exploited in many ways including wearing the heated liners under mitten shells for normal protection, then removing the shells for short-term work requiring dexterity.

There was clearly a design flaw in the prototype heated liner. Even a limited test with a small number of subjects revealed a significant problem with hot-spots. The cause of the problem was not identified, but we would tend to focus on the handling and flexing of the wires and connectors during dressing and movement to the chambers. The heated liners may be a promising design, but the problem with hot-spots, which may be related to subject activities during dressing, must be identified and corrected before the design will be suitable for general issue to a military population.

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